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This period of grant support was used to continue experiments on the preattentive processing of features, focusing on the role of attention in the integration of information across opposite directions of contrast. While unicontrast dots can be integrated in parallel across space and time to give rise to preattentive perception of either orientation or motion, attention seems to be required when the dots are of opposite contrast, consistent with the predictions of feature integration theory. A new method of dissociating preattentive and attentive processing through selective adaptation was explored.

The second main area of research concerned perception and visual memory for novel objects, using priming tasks to discover the nature of the representations formed either automatically or with attention. We discovered a surprising combination of plasticity and persistence in implicit memory: Unattended novel patterns apparently leave memory traces that are formed in a single presentation but persist across at least 200 intervening trials with other similar patterns. Yet no conscious explicit memory is available even immediately after the presentation.

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Technical Report: AFOSR Grant Number 90-0370
March 15, 1992 - February 28, 1993.

Principal Investigator: Anne Treisman
Department of Psychology
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General Organization

For the past twelve months, the people employed by the grant were Beena Khurana, as technical assistant and coordinator for the first three months, Ephram Cohen and Jonathan Segal as part-time programmers, Dorothy Sexton and Norma Sanchez as undergraduate lab assistants, and Brett De Schepper, Kathy O'Connell, and Ethan Newby (at different times) as graduate student R.A.'s. Since September, 1992, I have also taken on a post-doctoral student, Nilli Lavie, whose salary is funded by a Miller Fellowship from the University of California, Berkeley.

From September 5th, 1991 to August 15th, I was on leave at the Russell Sage Foundation, New York, where I continued to collaborate with my students in Berkeley, and to run experiments, communicating by e-mail with my assistants there. I also worked on several papers reporting experiments that we had completed and updated my reading on current relevant research. I returned to Berkeley in August, 1992 and spent the remaining time in this grant period there.

Research

We continued our work on a number of different projects relating to visual perception and memory for features and objects, exploring the processing that converts visual sensory data to representations of objects and events. The research falls into two main categories. (1) We carried out some new experiments on the preattentive processing of different features, using objects composed of elements that either shared the same contrast or were defined by opposite contrast or by texture or color boundaries, with the goal of determining the role of attention in processing shape across a variety of different surface "media". (2) We explored the effects of object representations, resulting from perceptual processing constrained by different task requirements on the re-perception of the same objects, either immediately, after a single presentation, or after multiple trials or long delays. We have been using various priming tasks to explore the visual memory traces formed by different kinds of perceptual tasks, and in particular how they are affected by attending globally to the display as a whole, or locally to each element in turn, or by suppressing one object in order to attend and respond to the relevant object in a superimposed pair.

1. Preattentive processing and apparent motion, with Todd Horowitz

In the previous technical report, I described some research I was carrying out, together with Todd Horowitz, on the role of attention in the perception of apparent motion. We followed up on earlier results showing that short range motion appears to be processed in parallel across the visual field, but that long range motion (over wider spatial and temporal separations) depends on focused attention (Cohen and Ivry, 1989). The short-range system is presumed to be based on low-level detectors early in the visual system. It is responsible for the perception of real motion as well as apparent motion over short displacements. The perception of motion over larger displacements is conceived of as a higher level system, more "cognitive" or inferential in nature (Braddick, 1980). We showed that when the elements composing the apparent motion alternate in contrast between darker and lighter than the background, even short range motion appears to require attention. Thus, search for a bicontrast target defined by a unique direction of motion produces latencies that increase with increases in display size whether the dots composing the trajectory are separated by one or by three dot widths (involving the short or the long range systems respectively).

This year we are testing a new prediction from the idea that short range parallel processing of apparent motion depends on specialized feature detectors whereas long range motion depends on attention. We test the effects of adaptation to a field of dots in motion on search latencies when either the target motion or the motion of the distractors is shared by the adapting field. If we find selective effects, depending on the adapted direction of motion, this would suggest the existence of dedicated feature detectors whose sensitivity has been reduced through habituation. It took us some time to find the appropriate conditions to maximise the effects, but it now seems that we are getting the predicted effect on short range motion. If so, we will test long range motion and bicontrast short range motion in the same way, to see whether there is any contribution from the adapted detectors to those forms of motion perception, or whether they depend on a separate and independent attention-based system.

This new method of testing the effects of selective adaptation on search, may prove a useful converging operation to distinguish attentional from feature-based processing with other types of displays besides those involving apparent motion.

2. Coding of orientation, with Kathy O'Connell

Kathy O'Connell and I continued the research on preattentive orientation coding described in my last Technical Report. We had previously tested search for targets defined by their orientation, defined in a number of different "media". Thus the orientation could be that of a line, an edge, a pair of dots and an illusory contour. We investigated whether the coding of orientation is shared across these different media, using a visual search task for targets defined by conjunctions of a particular orientation and a particular medium. When half the distractors share the target orientation in a different medium they should interfere with target detection if and only if the orientation code is shared by the two media. The results showed substantial effects of display size in search for conjunctions of orientation with lines and dot pairs of shared contrast, and with lines and edges, although both orientation and medium could be detected in parallel for targets defined by any one of these features alone. The orientation of bicontrast dot pairs (one black dot and one white dot on an intermediate gray background) could not be detected in parallel, however, and seemed to require focused attention to each item in turn.

In this past year we have carried out some further experiments exploring whether shared luminance contrast plays an essential role in defining orientation for dot pairs at the preattentive level. We gave subjects search tasks for orientation targets defined by virtual lines joining dot pairs with (1) very dim luminance contrast, (2) shared color at isoluminance, (3) shared texture boundaries with no overall difference in luminance, (4) bicontrast dot pairs with each pair containing one lighter and one darker dot on a grey background. All except the bicontrast pairs gave parallel coding, with the task differences showing only in the intercepts of the search functions and not in the slopes. Thus orientation appears to be available in parallel, with global attention, regardless of the discriminability of the boundaries; the latter affects the speed of this global discrimination for the presence of targets defined by different media, but does not alter the optimal deployment of attention. Preattentive coding of orientation seems not to depend only on the presence of clear luminance differences; it is available also with much reduced luminance contrast, or with color or texture contrasts, but it can be prevented by the reversal of contrast within dot pairs. One possible account may be that virtual lines are available within any single feature map (luminance, color, texture) but that darker and lighter contrast are represented in separate feature maps at the level at which the orientations of virtual lines are represented. Integration across contrast differences would then require focused attention, just as integration across other separate feature maps does in conjunction search tasks.

The dissociation we find between effects on the slope of the search function and effects on the intercept is also of interest. It is consistent with the distinction between attentive processing of conjunction-defined stimuli and preattentive but slow processing of low discriminability feature-defined stimuli. A display of dim dot pairs is processed more slowly than a display of bright dot pairs, but the processing appears to remain parallel, (i.e. unaffected by increases in the number of non-target items).

Kathy O'Connell has also begun her dissertation project, which will be on the effects of attention in the "shooting line illusion" described by Shimojo.

4. Preattentive guidance of attention in patients with neglect, with Marcia Grabowecky.

Marcia Grabowecky completed her doctoral dissertation last Summer and was awarded the degree of Ph.D. She has since taken up a post-doctoral appointment at the University of California, Davis, with Michael Gazzaniga.

Her dissertation followed up on some research that she had done together with Lynn Robertson and me on the effects of preattentive processing in patients with parietal lesions producing unilateral neglect. We explored the possibility that perceptual grouping might contribute to the definition of a task-appropriate reference frame, even when the grouping stimuli were presented in the patients' neglected field in which they were unable to find targets when explicitly and consciously looking for them. We used a visual search task in which patients with unilateral visual neglect (5 with right-, 2 with left-hemisphere damage) searched a diamond-shaped matrix for a conjunction target which shared one feature with each of the two types of distractor elements. Additional irrelevant grouping stimuli appeared as flanks either on the left, right, or both sides of the central matrix, and significantly changed performance in the search task. As expected, when flanks appeared only on the ipsilesional side a decrement in search performance was observed, but the further addition of irrelevant contralesional flanks actually reduced the decrement and returned performance to near baseline levels. These data suggest that flanking stimuli on the neglected contralesional side of visual space can influence the reference frame by grouping with task-relevant stimuli, and that this preattentive influence can be preserved in patients with unilateral visual neglect.

Marcia continued this work with patients, and also with normal subjects, exploring the influence of similarity at the feature level between flanking stimuli and the search displays. The results showed little effect of similarity of color and shape, but instead appeared to reflect a form of grouping at the level of figure-ground segregation. Her idea was that the center of mass of a display (determined by the density and distribution of the individual elements it contains) may preattentively control the direction of attention. Earlier research has shown that saccades are directed towards the center of mass of a group of elements arrayed in the periphery: thus, saccades to a clearly discriminable target overshoot if additional elements appear beyond them and undershoot if the extra elements are between the target and the fixation point (Coren & Hoenig, 1972). Marcia's results provided some support for the idea that manipulations of the center of mass of a display, which influence saccadic eye movements, also influence the movement of attention both in normal subjects and in parietal patients, even when the elements that shift the center of mass fall in the neglected field.

5. Occlusion inferences and feature integration; research by Beena Khurana

Beena Khurana also completed her doctoral dissertation last Summer and was awarded the degree of Ph.D. She has since accepted a position as Assistant Professor at Cornell University.

Her dissertation concerned the effect of cues to three-dimensional structure on the perception of the color of line drawings. Her research suggested that occlusion structures are available pre-attentively and can modify the subsequent synthesis of other features such as the color of contours. Under conditions of attention overload, contours whose color was inconsistent with the occlusion structure suggested by the shapes of the figures were frequently altered by illusory migration of colors from other parts of the displays, to make them consistent with the perceived interpretation of occlusion. Experiments with two-dimensional control stimuli showed that the constraint imposed by the occlusion structure operates not at the level of local line continuity but rather at the level of global figural occlusion. The findings suggest that the perceived colors are affected by the three-dimensional structure signalled through luminance information.

Beena then ran two more experiments to test this hypothesis. When the figures were presented at isoluminance, so that the shapes were defined only by their colors, the illusory migrations were much reduced, suggesting that the top-down control from the three-dimensional interpretation has less effect when the constraining information comes on the same channel as gives rise to the illusion. Secondly, she repeated the experiment using bicontrast stimuli, with some contours in black and some in white on a grey background. Again the illusory migrations were reduced, suggesting that the figural information for occlusion may have its effects at some level that precedes the integration of opposite contrasts into a unified three-dimensional structure. These experiments are relevant to the current debate about the relations between the magnocellular pathway (luminance) and the parvo-cellular pathway (color), and they explore the perceptual implications of the neural independence of on and off pathways in the visual system.

6. Object perception and attention in negative priming experiments, with Brett De Schepper.

Perhaps the main emphasis in my research this year has been on visual memory for the episodic token representations that subjects form in one presentation for novel shapes that they have never seen before, and on the role of attention in determining the nature of these memory traces. We explore the process of seeing without identification, in order to bring out a distinction between object types - the stored descriptions or models of previously seen objects to which we match present stimuli, - and object tokens - the temporary representations which mediate the perception of a particular stimulus, whether known or unknown, in its current color, illumination, distance, viewing angle and orientation (Kahneman & Treisman, 1984).

One task that Brett De Schepper and I have used to explore the formation and memory for object tokens is the negative priming paradigm, first developed by Greenwald (1972) and later elaborated by Neill (1977) and by Tipper and his colleagues (Tipper, 1985; Tipper & Driver, 1988). Negative priming is shown when a stimulus which was irrelevant on one trial becomes the relevant stimulus on the next. The switch often results in a slower response than is made to a control stimulus that was not previously unattended, as if the irrelevant item had been inhibited to prevent it from competing for response. The inhibition then lingers into the next trial and has to be lifted before the new response can be made.

In our earlier experiments, we showed that a novel object with no pre-existing representation in memory gave at least as much negative priming as familiar letters or pictures. This result would suggest that episodic tokens are formed on a trial by trial basis to represent each current, unfamiliar object, even when it is not the relevant item controlling the response. Thus, inhibition can be attached to meaningless visual representations the first time they are presented and without any attention being paid to those representations.

This year, we have explored how long these token representations remain in memory, by looking for negative priming at different lags, separated by varying numbers of intervening trials. To our surprise, we find that negative priming is as strong at a lag of 200 intervening trials as it was at a lag of 1. On the other hand, when we test explicit memory for the same shapes in the same paradigm, by asking subjects on interleaved trials to do a forced choice recognition on both the attended and the unattended shapes, we find absolutely no conscious explicit memory for the unattended shapes. It is interesting to note that Rock and Gutman also found no explicit memory whatever for the unattended stimuli in their experiment with similar overlapped pairs of meaningless shapes. They concluded that attention is necessary to identify shapes and to lay down traces in memory. Our results show that this is not the case, although attention does seem to be required to allow explicit conscious access to those representations. It seems that the negative priming task may lay down traces in a separate memory system that is not accessible to voluntary explicit retrieval (Musen & Treisman, 1990; Schacter, Cooper & Delaney, 1990). Moreover the traces must be detailed enough to allow discrimination between 250 random meaningless closed shapes, since we found the effect on the median latencies as well as on the means. This rules out the possibility that the effect is due just to a few highly memorable items. Our negative priming effects imply a remarkable combination of plasticity and persistence at some level of the visual system.

Connectionist nets must usually trade off one of these features against the other, with faster weights serving a different function from the slower ones (Hinton, 1990). Here, on the other hand, speed of formation and persistence seem to be associated with the same memory traces.

We are now trying to push the tests to the limits of the memory by extending the lag beyond 200 items. The results suggest that there may be some decrease beyond this point, but the critical variable may be the total number of shapes presented rather than the duration per se, because with these very long lists, we seem to get a drop in negative priming at lag 1 as well as lag 300 or 400. It may be that as we increase the total set of shapes (each seen once only) we inevitably decrease the discriminabilty from their most similar counterparts, and that we reach the limit of the resolution available in this implicit memory for patterns.

Another question we are asking is whether there is any cerebral lateralization of this visual store for novel meaningless patterns. We present the prime and probe either to the left or to the right hemisphere and measure negative priming separately for each hemisphere. We are also varying the complexity of the shapes to see whether there is any interaction with the hemisphere tested. These experiments are still under way.

7. Attention and object tokens in search automatization, with Amy Hayes

The other main paradigm I have been using to study visual memory for object tokens has been a visual search task for feature and for conjunction targets. When extended practice in search is given, substantial changes occur. Complex shapes may eventually appear to be detected automatically (Vieira & Treisman, 1988). On the other hand there is very little transfer from this learning to other tasks using the same overlearned shapes. We suggested that the automatization we observed might depend on specific object tokens, traces left by each experience of a particular target display, as in Logan's exemplar model of skill acquisition (Logan, 1988). The research in this section explored some effects of the type of perceptual processing on the memory traces that are evoked, both in long term practice effects and in short term repetition priming.

In the first two years of the grant, we looked mainly at the long term learning that underlies search automatization. The framework we explored assumed that when we look at a scene, we have the option of dividing attention to process it globally, or of focusing attention on one object at a time. We suggest that when attention is divided, all the features <u>within</u> the attention window are processed in parallel, but only their global layout is available. The presence of a single unique feature will "pop out" of a display, but it may be poorly localized and its particular conjunction of other features will not be available until attention zooms in to that element alone. To manipulate attention, Amy Hayes and I used two different visual search tasks: search for targets defined by a single feature and search for a conjunction of features. In conjunction search, attention is directed to an object and all its features are automatically integrated with their location and with each other. On the other hand, in feature search no individuated object tokens are needed. If skill acquisition depends on reactivating earlier object tokens, we therefore expect more specificity in conjunction than in feature search. In order to test the effects of initial perception on re-perception and automatization, we introduced contingencies between some of the targets and their locations. We found a large difference between conjunction and feature search in the specificity of what was learned. As predicted, there was a very large effect of location consistency on conjunction search, which increased across sessions, and a much smaller effect on feature search, which actually decreased across sessions.

In two further experiments, we looked at contingencies between the targets and other irrelevant features besides location, to see if we could find differences in specificity on other dimensions as well. We did indeed find a consistency benefit for the feature-biased target when it appeared with its associated feature, as well as replicating the consistency benefit for the location-biased target when it appeared in its associated location. On the other hand, in a similar search experiment with feature rather than conjunction targets, the consistency benefit of associated features averaged only 1.5% and had disappeared by the third session.

We next tested the effects of distractor, as opposed to target, consistency on perceptual learning. We varied what proportion of the distractors appeared in their most frequent positions in each display and found a substantial benefit when the distractors were consistent across trials as well as when the target was repeated. Again, the effect was much larger in conjunction than in feature search, as it should be if each distractor is attended in order to ensure that its features are not conjoined to fit the target definition. The results support the idea that the effects of practice in the automatization of search are mediated by an accumulation of specific memory traces whose nature varies with the particular type of perceptual processing required by the task.

In the present grant period, we have been comparing the specificity of the traces in the short term, immediately after_they have been formed, when the task is feature search and when it is conjunction search. We use the same search tasks, but test trial to trial priming instead of long term learning. We had previously done a post hoc analysis of the trial to trial repetition effects in the same experiment in which we tested long term learning. We found some intriguing differences, which we wanted to follow up.

For conjunction targets, there seemed to be a change between the short and the long term measures in what produces a cost. A mismatch on location when the location-biased target appeared in an unexpected location was very costly in the long term measure, whereas changing the location produced no cost in trial-to-trial priming. On the other hand, in short term priming, there was a slight (though not significant) cost of changing the target when the location was repeated. This pattern of costs and benefits suggests an asymmetry between the retrieval cue and the content of what is retrieved. Early on, the location of the object is a powerful cue for retrieval. If the currently attended location matches that of the previous target, its content is retrieved and produces a benefit when the targets match and a small cost if they do not. Once a token has been retrieved, however, the location information stored with it may also become salient and substantially delay the response if there is a mismatch with the location of the presently attended object, or speed it up if both target and location match.

Because that experiment was designed to test the learning of long term consistencies, there were inevitable confounds which prevented our collecting data in some of the critical conditions. This year we ran two separate experiments testing repetition priming, comparing reaction times as a function of what is repeated in the current trial from the one preceding it. We compared responses to the identical target in the same location or in a different location; the same target with one or with two features changed; a different target in the same location, with one or two irrelevant features the same, or a target which differed in every possible way. In this version of the experiment, no expectancies could be formed because the targets were randomly selected on every trial and the classification of conditions was done after this random selection was made. Again we compare conjunction and feature search to see whether the short term priming shows the same difference in specificity as the long term learning in the previous series of experiments. The results are currently being analyzed.

Early selection and attentional load

My postdoctoral student, Nilli Lavie, has been working in my laboratory since last September. She is testing the hypothesis (which I had proposed some time ago, Treisman, 1969) that attention can be selective only when the load is sufficiently high that the subject would be unable to process all the information if he or she tried to do so. In other words, whatever capacity is available must automatically be used. Attention can affect perception only by the choice of where that capacity is allocated when competing demands are made on it.

Nilli has carried out two experiments testing that claim, using the Eriksen & Eriksen (1974) flanker paradigm in which a choice response is made to a target item, flanked by either compatible, incompatible or neutral items. The prediction is that the more difficult and attention-demanding the target task is, the less interference or facilitation there will be from the flanking distractors. Nilli varied the load on the target task in two different ways: by adding irrelevant nontargets, varying the display size in which the target is embedded, or by making the response conditional on the analysis of another adjacent item. In each case, she controlled the discriminability of the distractor and its spatial separation from the target, to ensure that there was no physical interaction with the load manipulation in the target task. In both experiments, she confirmed the prediction that the high load condition would reduce the interference from the incompatible flanking distractor. The result is counterintuitive, since the harder task is the one that suffers less damage from the distracting element, but it fits the hypothesis that attentional selection is efficient only in conditions where the target task requires most of the available capacity.

Memory and the feeling of knowing, by Margaret Wilson

My graduate student, Meg Wilson, has been working on her dissertation project this year. She is investigating subjects' awareness of the information that they have in memory and of its sources. She has shown that when subjects are forced to generate an answer to a general knowledge question, they are later more confident that they know the answer, whether it is correct or not. She is now planning to compare the effects of an item that the subjects themselves generate with those of an item that the experimenter supplies and that they simply judge as true or false.

Severai papers describing these projects have been written, and are either in press, submitted, or under revision. They are listed below. For the remaining period of grant support, we will continue to work on these projects and develop others that arise from them. We are grateful to AFOSR and ONR for the financial support which makes the research possible.

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Grabowecky, M., Robertson, L.C., & Treisman, A. (1993) Preattentive processes guide visual search: Evidence from patients with unilateral visual neglect. Journal of Cognitive Neuroscience, in press.

Papers in preparation

O'Connell, K., & Treisman, A. Preattentive coding of orientation. Under revision.

Horowitz, T., & Treisman, A.M. Attention and apparent motion.

Treisman, A., & Hayes, A. Location and feature specificity in search for features and conjunctions.

DeSchepper, B., & Treisman, A. Novel visual shapes in negative priming.

Papers presented

April, 1992. Colloquium at M.I.T.

May, 1992. Colloquium at Princeton.

May, 2992. Poster (with Todd Horowitz) at ARVO meeting, Sarasota, Florida.

July, 1992. Invited paper to symposium on Attention, International Congress of Psychology, Brussels, Belgium.

October, 1992. Paper to Cognitive Science Program, Berkeley.

November, 1992. Talk to Cognitive Science group, Stanford University.